CRH SSD
NOVEMBER 1996

CENTRAL REGION TECHNICAL ATTACHMENT 96-08

The Milwaukee Snowstorm of November 27, 1995

Wesley D. Browning
National Weather Service Forecast Office
Milwaukee/Sullivan, Wisconsin

1. INTRODUCTION

This paper uses GOES 8 visible imagery, WSR-88D data, and gridded model output to explore some possible mesoscale causes of narrow bands of heavy snow that affected Milwaukee, Wisconsin on November 27, 1995. On that date, a winter-like storm produced a swath of 6 to 14 inches of snow across much of central and southern Wisconsin (Figure 1). A band of moderate to heavy snow, about 80 miles wide, formed early in the day from southwest Wisconsin northeastward to near Green Bay. By late morning, southeast Wisconsin was receiving only light snow, and satellite and WSR-88D imagery showed that the heavy snow remained well north of the city of Milwaukee; however, narrow bands (5 to 10 km wide) of heavier precipitation were beginning to form to the south in northern Illinois. At 1921 UTC (1:21 p.m. LST), thunder and moderate snow began at Milwaukee. Heavy snow accompanied by lightning and thunder was observed shortly after that, and the heavy snow lasted until 0056 UTC 28 November (6:56 p.m. LST). About 7 inches of snow fell in approximately 5 hours, and near-blizzard conditions paralyzed the city of Milwaukee. As fate would have it, the heavy snow moved into the city during the afternoon rush hour. The resulting gridlock was the worst in over 40 years in Milwaukee, as commutes that normally took 30 minutes averaged 3 to 4 hours. Over 1000 traffic accidents occurred, and the Milwaukee airport was closed for about 16 hours.

2. SYNOPTIC OVERVIEW

This study utilized gridded model output from the 0000 UTC and 1200 UTC 27 November AVN, NGM, and ETA numerical models, along with archived WSR-88D data from Milwaukee (KMKX) and Davenport, IA (KDVN). In addition, RAMSDIS GOES 8 visible imagery was used.

The sea level cyclone followed a track traditionally favorable for heavy snow in southern Wisconsin (Figure 2). At 300mb, Wisconsin was in the left exit region of a jet streak centered over Missouri, and in the right entrance region of a jet streak centered over Nova Scotia (Figure 3). The ageostrophic circulations associated with these jet streaks may have coupled over Wisconsin, thus enhancing upward, jet-induced vertical motion.

Quasi-geostrophic analysis using Q vectors (Figure 4) implied the presence of upward vertical motion over southern Wisconsin at 500mb, 700 mb, and 850mb, with the largest rising motion implied at 850mb. Recognizing the lack of thermal advection by the ageostrophic wind in the Q vector approach, examination of the layer mean Petterssen frontogenesis function (which uses the total wind) from 1000mb to 850mb gave a complete look at low-level frontogenesis (Figure 5). The maximum frontogenesis took place in southeast Wisconsin and northeast Illinois at forecast hour 6 (1800 UTC). This lower tropospheric frontogenesis may have been forced by the jet coupling discussed previously, and likely focused and enhanced upward motion over Southern Wisconsin. Clearly defined model forecasted ageostrophic circulations, as shown in Figure 6, placed Milwaukee near the axis of strongest upward vertical motion. Using this model output, it appeared likely that a significant precipitation event would occur over Southern Wisconsin.

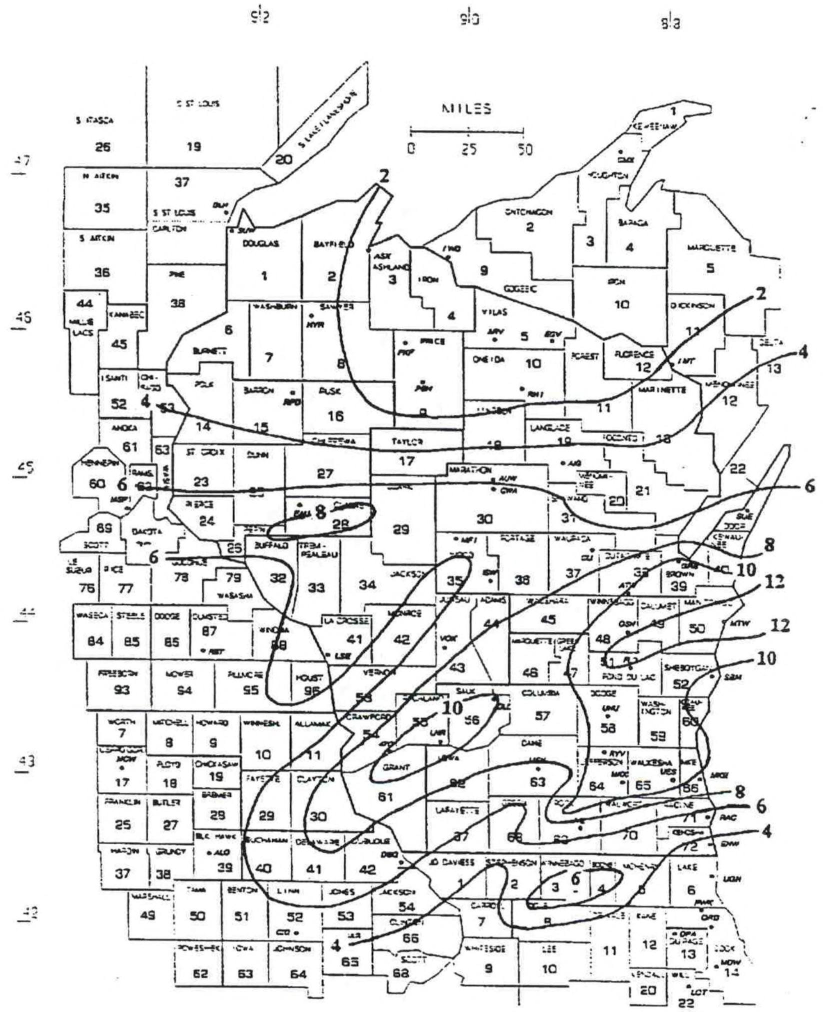

Figure 1. Storm total snowfall in inches.

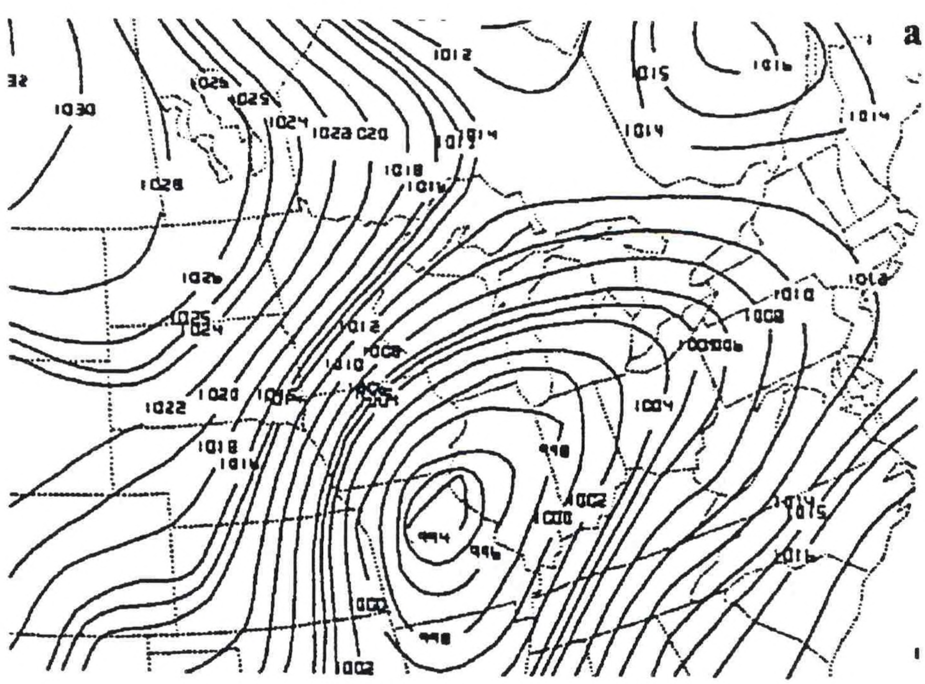

Figure 2a. Mean sea level pressure (mb) at 1200 UTC 27 November from the correlative NGM model initializations.

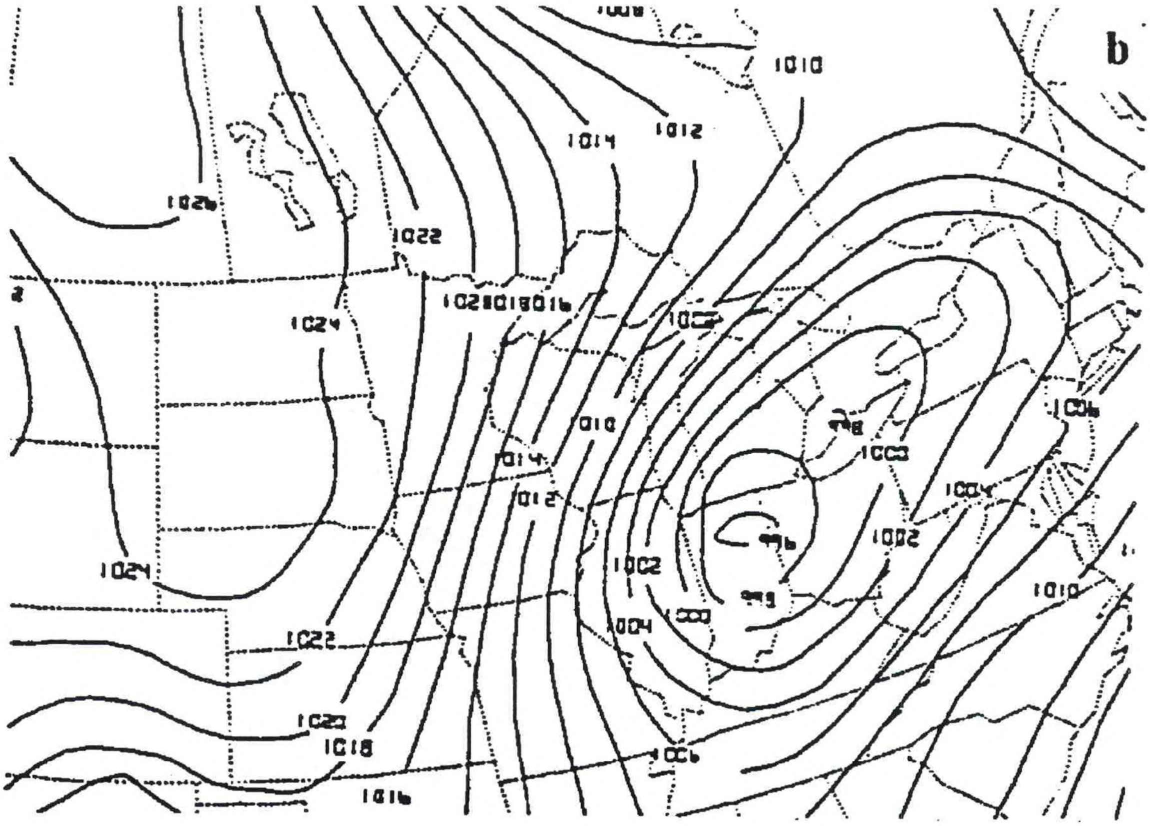

Figure 2b. Mean sea level pressure (mb) at 0000 UTC 28 November from the correlative NGM model initializations.

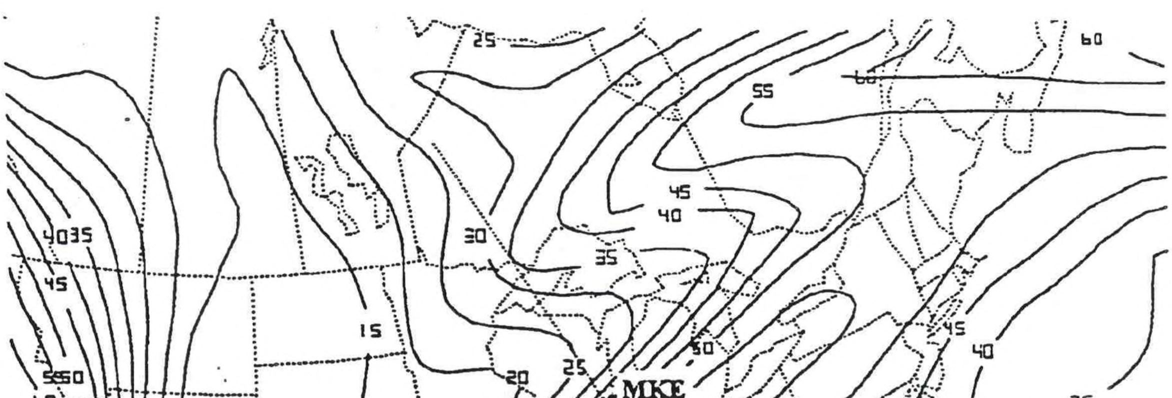

Figure 3. Isotachs (ms^{-1}) at 300mb from the NGM 6 hour forecast, valid 1800 UTC 27 November. Dotted line indicates trace of cross-section shown in Figure 6.

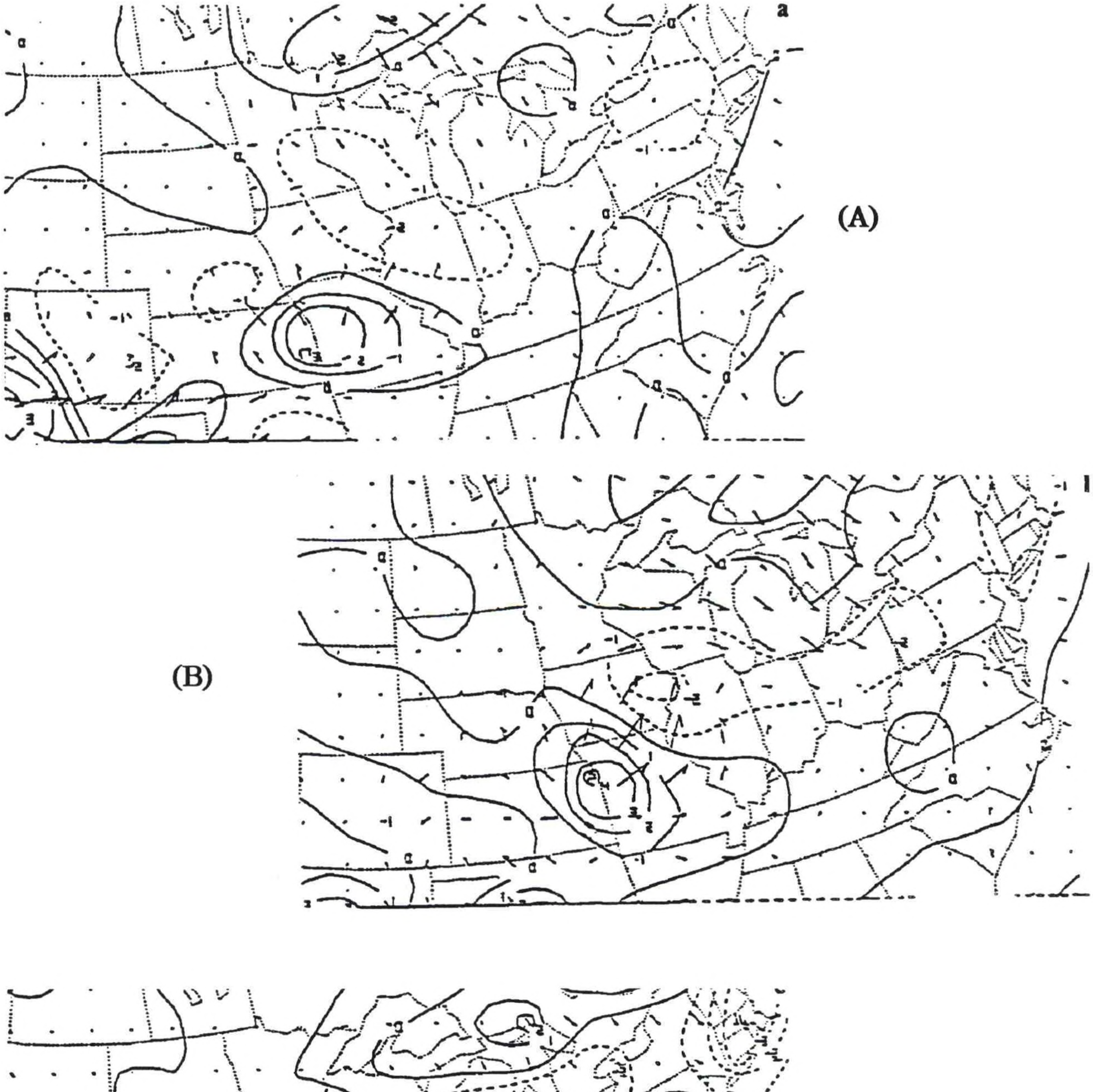

Figure 4. NGM 6 hour forecast of Q vector divergence (10^{-18}m $PA^{-1}m^{-2}s^{-1}$) for 1800 UTC 27 November at 500mb (a), 700mb (b), and 850mb (c).

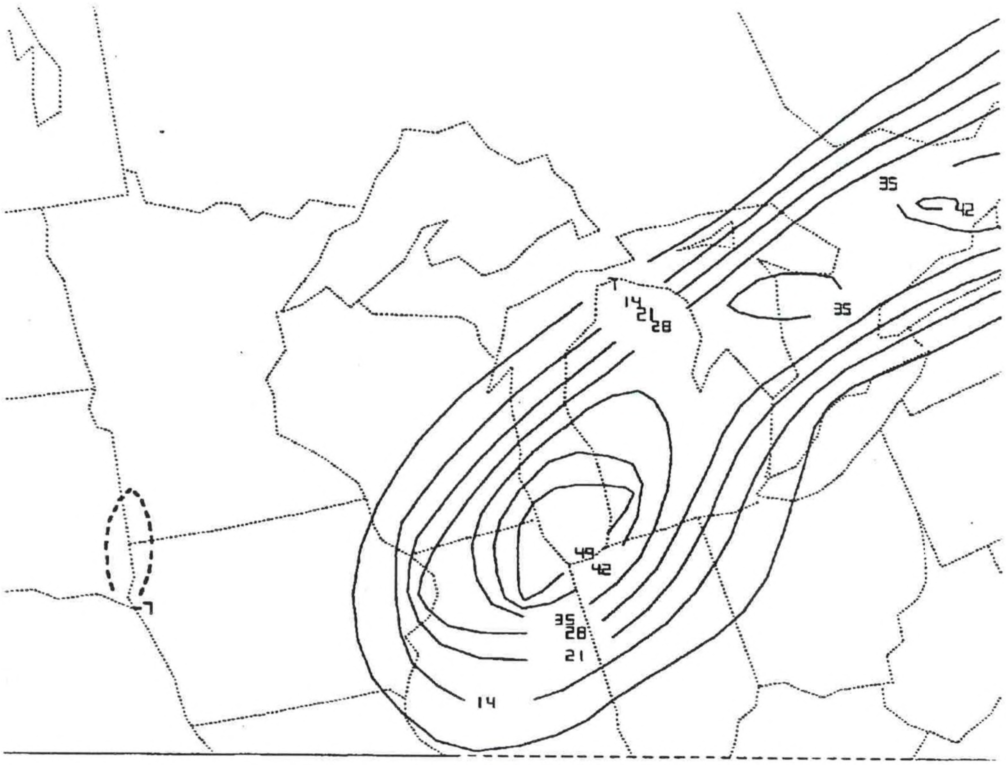

Figure 5. NGM 6 hour forecast, valid at 1800 UTC 27 November of the 1000mb to 850 mb layer mean Petterssen frontogenesis function (10^{-14} m $Pa^{-1}m^{-1}s^{-1}$). Positive values indicate frontogenesis.

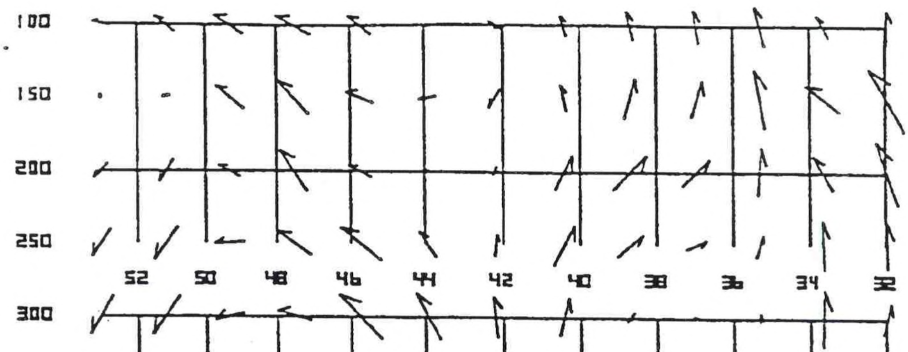

Figure 6. Relative ageostrophic circulation along cross section shown in Figure 3. Direct circulation centered near 500mb is on the left, and indirect circulation is on the right. The approximate location of Milwaukee (MKE) is shown.

3. MESO-β SCALE ANALYSIS

While the model output shown did identify southern Wisconsin as the area most likely to receive heavy snow, a closer look at visible satellite imagery and WSR-88D data indicated the evolution of narrow bands of snow. These bands produced heavy snow accumulations well to the south of the primary synoptic snow band.

Several recent case studies have associated bands of winter precipitation to the occurrence of conditional symmetric instability, or CSI (Bennetts and Hoskins 1979; Sanders and Bosart 1985; Emanuel 1988; Moore and Blakely 1988; Browning 1995). CSI can result in narrow (typically a width to height ratio of about 2:1) bands of moist slantwise convection. The advent of gridded numerical model output has allowed for relatively easy diagnosis of CSI. Cross sections oriented perpendicular to the thickness field (thermal wind) are constructed, taking care that the cold side is on the left. Areas where the slope of a θ_e surface is greater than the slope of a momentum surface ($\delta\theta_e/\delta z|_M < 0$) are indicative of the potential for CSI.

Figure 7 shows cross sections through Wisconsin into northern Illinois. These sections were constructed from the model initial conditions (forecast hour 00) of the November 27, 1200 UTC model runs. The ETA model output (a) indicated a convectively unstable layer ($\delta\theta_e/\delta z<0$, prone to upright convection) generally between 850 mb and 700mb, and to the south of about 42°N. Between 42°N and 43°N, where $\delta\theta_e/\delta z<0$, there existed a narrow zone (shaded) where $\delta\theta_e/\delta z|_M<0$ (near the 309 K isentrope, which was added based on more detailed cross sections). This is where CSI was possible. The NGM model output (b) showed a more extensive zone of potential CSI, from just south of 42°N, northward to near 43°N. On the other hand, the AVN model output (c) did not indicate a definite possibility of CSI. The output showed a sharp transition from a convectively unstable atmosphere centered near 800mb (from about 41.5 N southward), to a convectively stable atmosphere where $\delta\theta_e/\delta z|_M=0$ (neutral to slantwise convection).

Satellite and radar data during the late morning and afternoon indicated the formation of narrow bands of precipitation over northern Illinois and southern Wisconsin, generally in the area where the ETA and NGM model cross sections showed CSI was a possibility. Radar images from Davenport and Milwaukee (Figures 8 and 9) indicated a broad area of snow extending from eastern Iowa northeastward to between Milwaukee and Green Bay. This area was moving slowly northward, and only light snow was reported at Milwaukee. To the south, narrow bands of precipitation were indicated from northwestern Illinois to southern Lake Michigan. GOES 8 visible imagery at 1715 UTC (Figure 10) clearly displayed the convective towers associated with these narrow bands, which the model output depicted to be parallel to the thermal wind. About one hour later, at 1815 UTC, these bands had intensified and moved northward. As illustrated in Figure 7, output from all 3 models indicated that the atmosphere was convectively stable ($\delta\theta_e/\delta z<0$) in the area where the bands intensified (north on 42.5 N, which is the Wisconsin-Illinois state line), so it is unlikely that the bands were a result of the release of potential instability. Figure 11 showed the bands stretching from just south of Dubuque to just south of Milwaukee. The visible image from 1815 UTC (Figure 12) again indicated the convective character of these bands. Thunderstorms moved steadily northward through the afternoon, reaching Milwaukee at 1921 UTC, when thundersnow began. Near blizzard conditions continued until 2200 UTC.

4. SUMMARY

Numerical model output, WSR-88D data, and visible satellite imagery indicated that the snowstorm that paralyzed the city of Milwaukee on November 27, 1995 was likely the result of a strong jet-induced ageostrophic circulation, which was enhanced by low level frontogenetical forcing and focused into narrow bands, possibly due to CSI. Access to the gridded model output makes it possible to diagnose areas prone to CSI. While model forecasts of CSI will not delineate the exact band locations, a general area of concern can be identified and then closely monitored using WSR-88D data and satellite imagery.

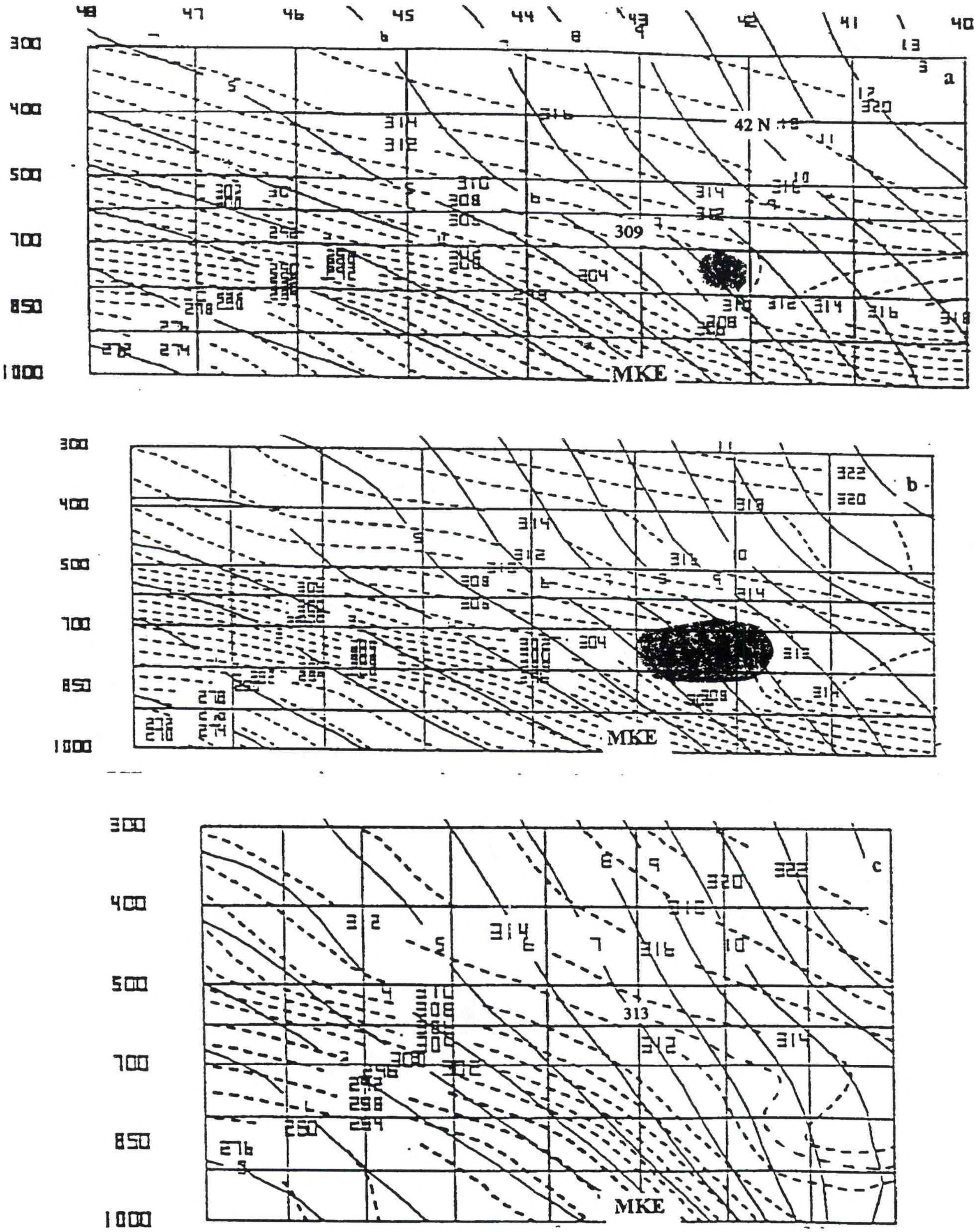

Figure 7. Cross sections of the model output from the ETA (a), the NGM (b), and the AVN (c) through southeast Wisconsin (Milwaukee is labeled) at 1200 UTC 27 November. Momentum surfaces (m s^{-1}) are solid, and θ_e surfaces (K) are dashed. θ_e contours 309 K (a) and 313 K (c) were added for clarity. Shaded areas are where CSI is possible.

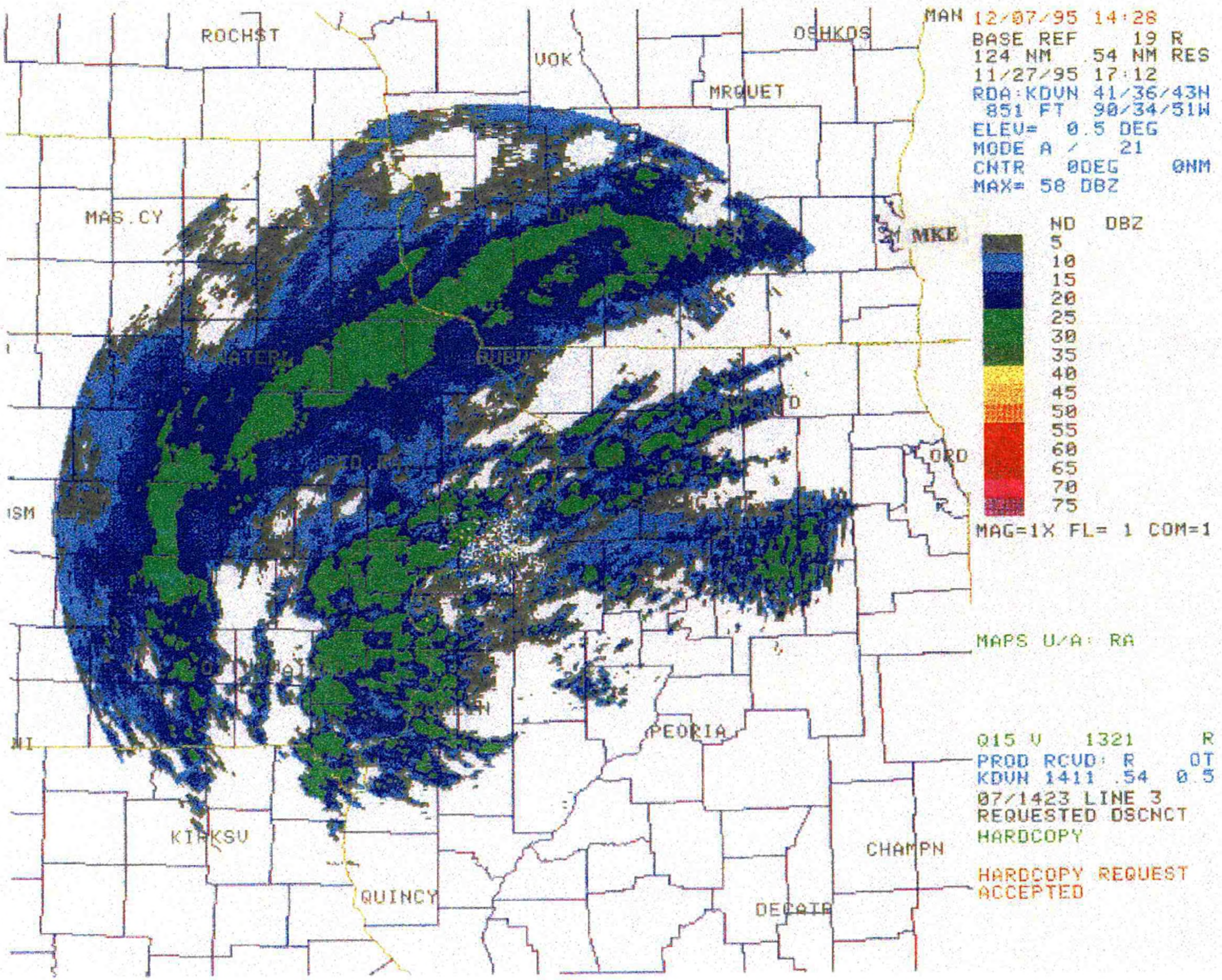

Figure 8. WSR-88D 0.5 degree reflectivity image from Davenport, Iowa at 1712 UTC 27 November 1995. Note the convective bands of precipitation over northwestern Illinois.

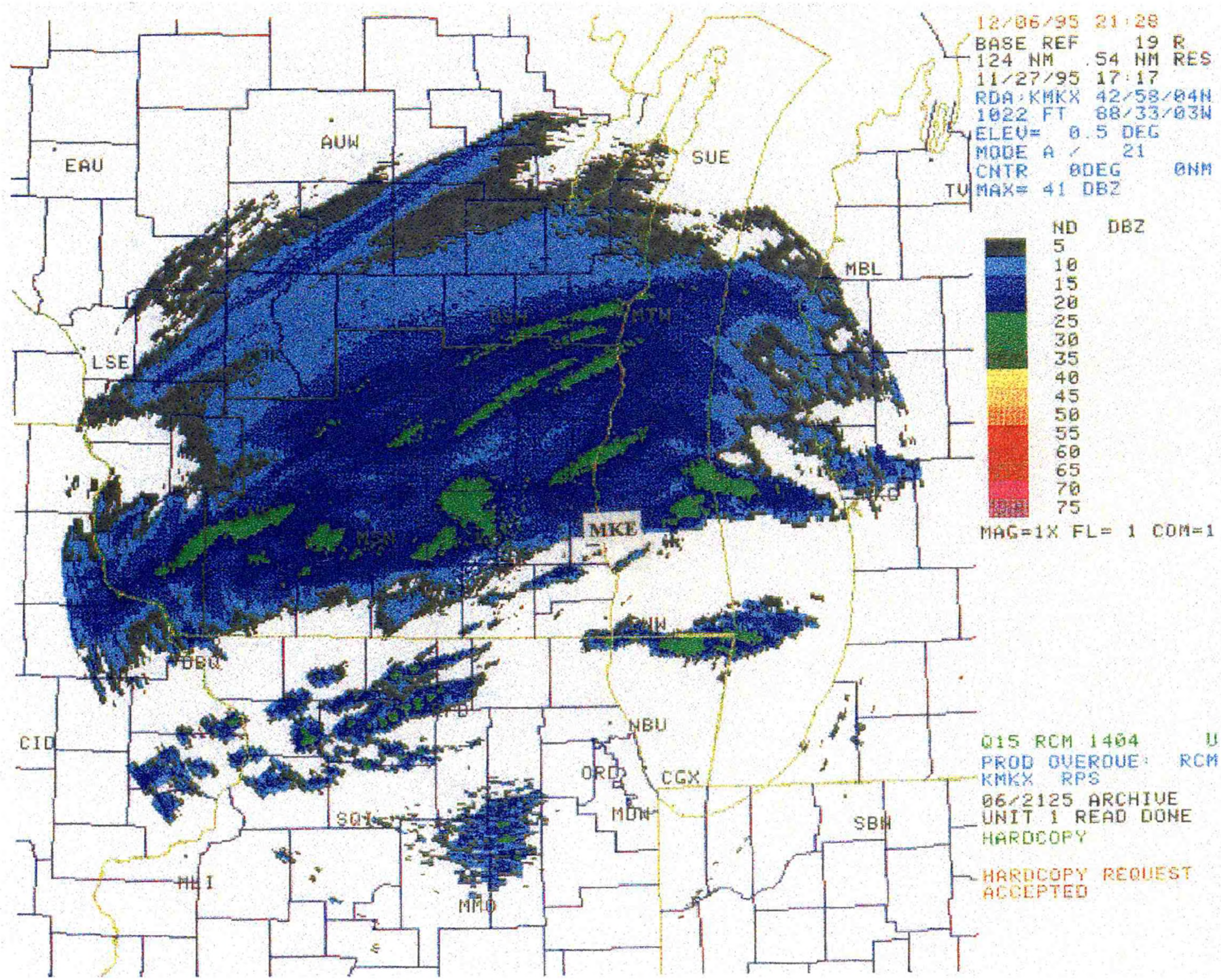

Figure 9. WSR-88D 0.5 degree reflectivity image from Milwaukee at 1717 UTC 27 November 1995. Synoptic snow band is just north of Milwaukee, while convective bands of precipitation are shown over northern Illinois, eastward to southern Lake Michigan.

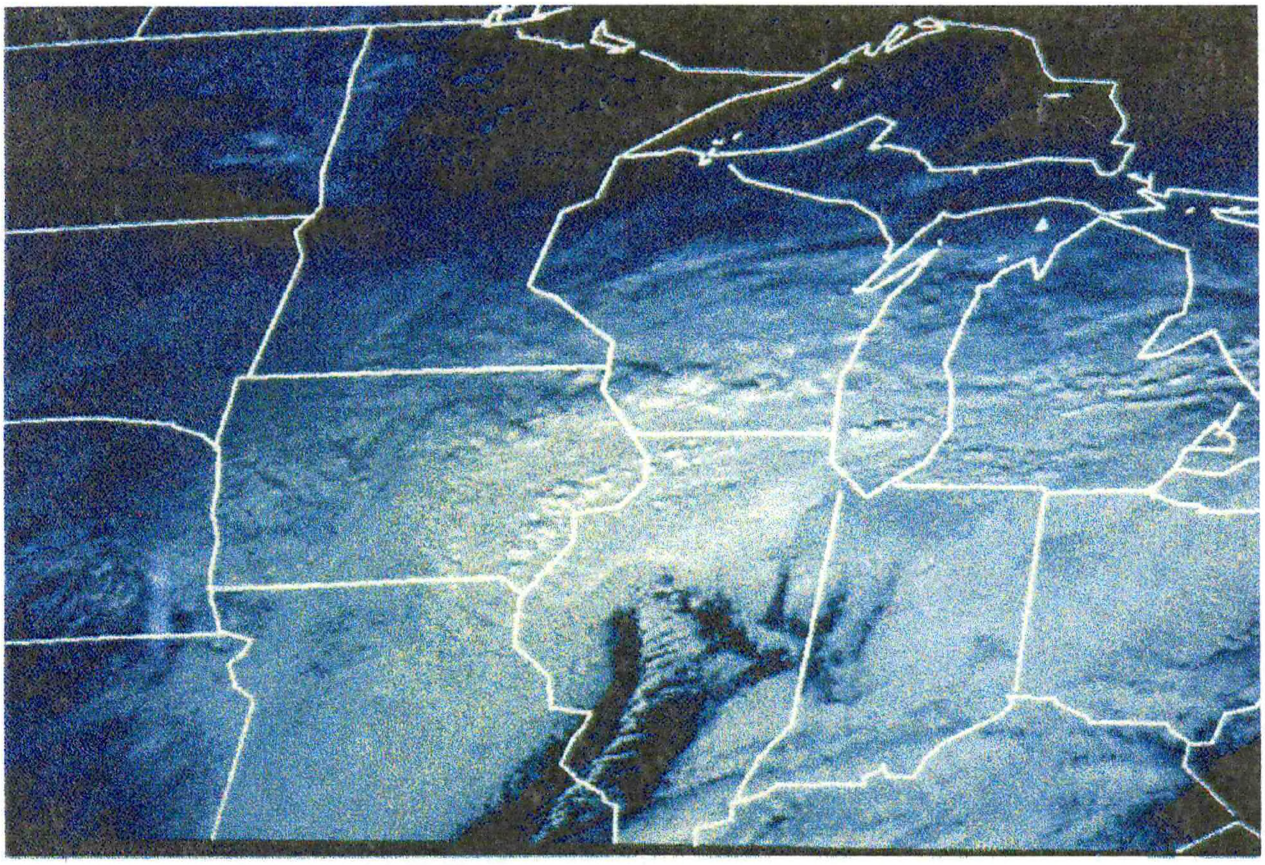

Figure 10. GOES 8 visible image at 1715 UTC. Note the convective bands of precipitation over northern Illinois.

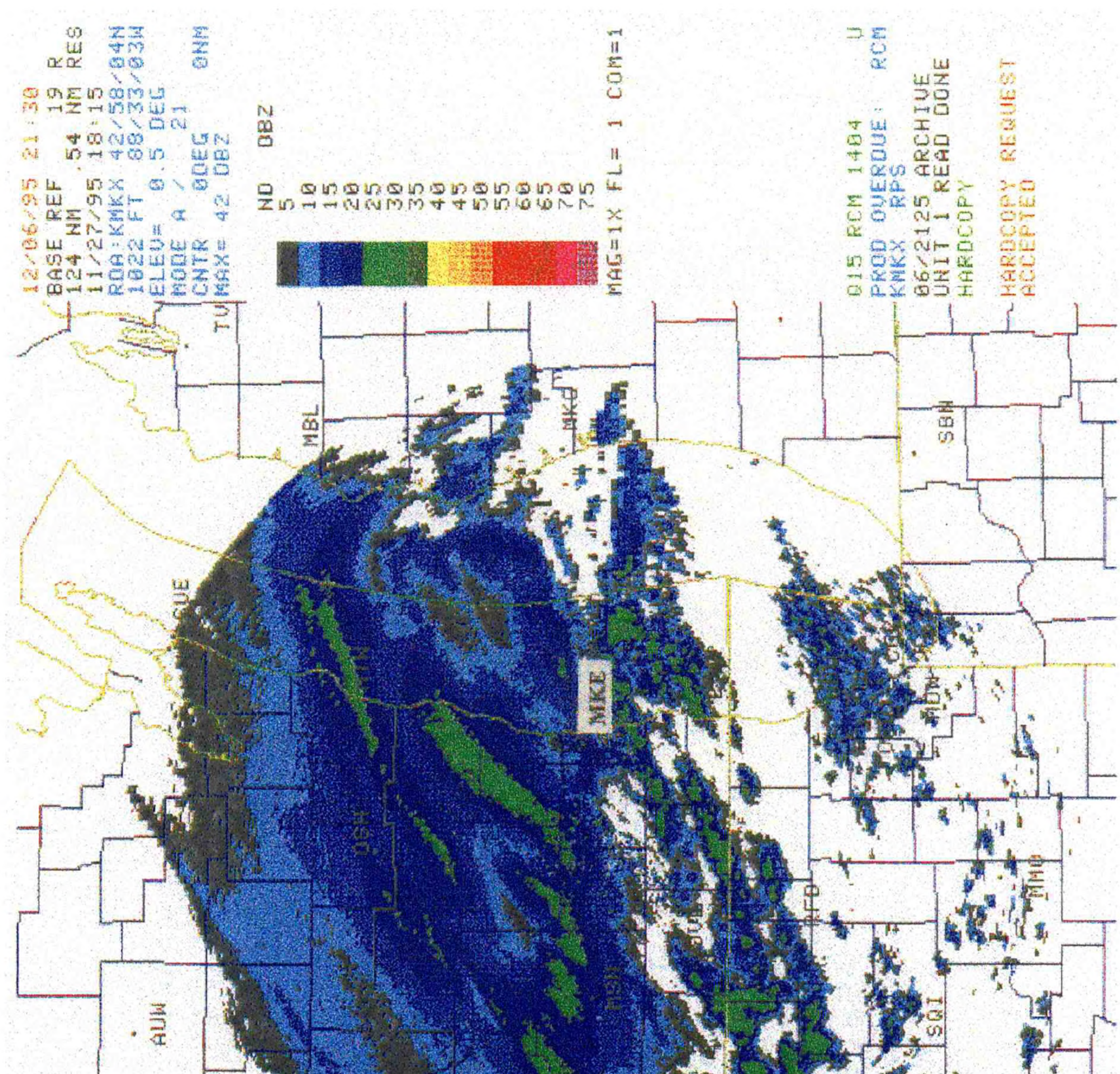

Figure 11. WSR-88D 0.5 degree reflectivity image from Milwaukee at 1815 UTC. Three well defined convective bands of snow extend from just south of DBQ to just south of MKE.

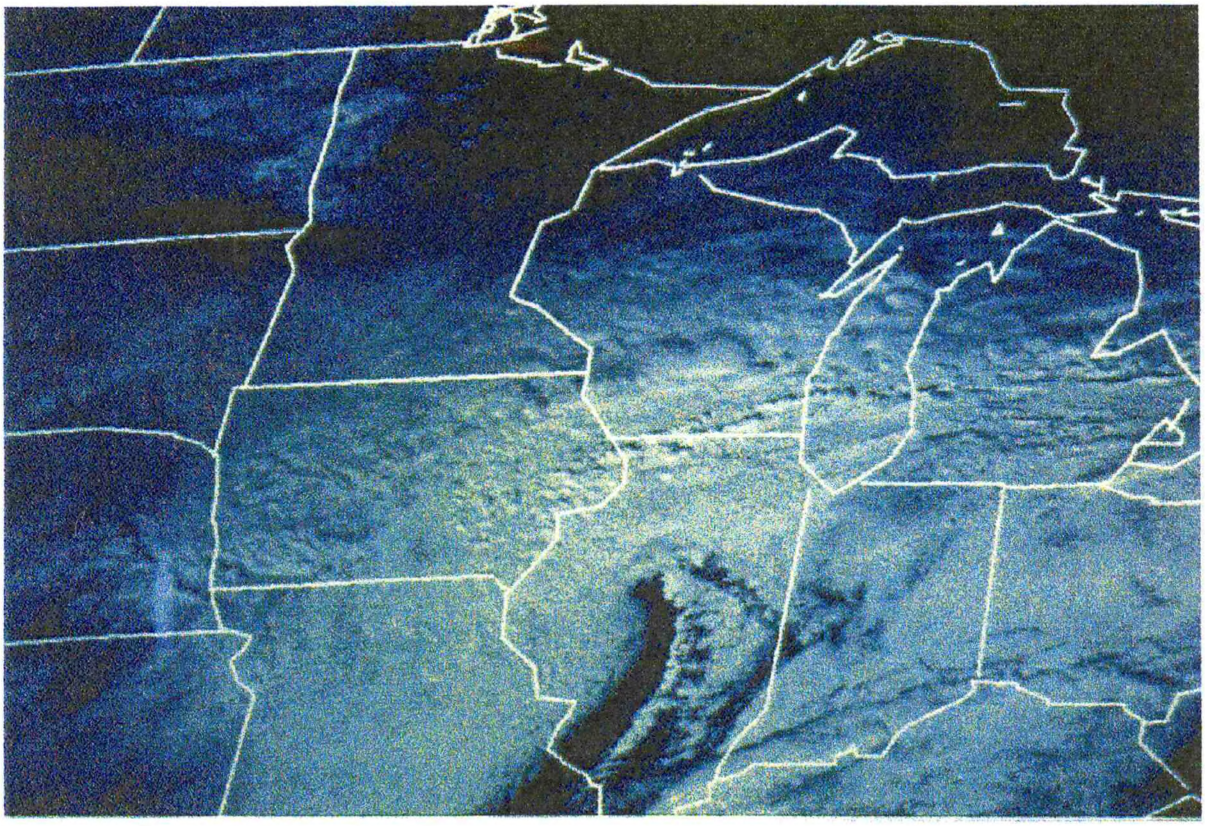

Figure 12. GOES 8 visible image at 1815 UTC. Convective bands are visible over northwestern Illinois, northeastward into southern Wisconsin.

5. REFERENCES

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